ZEMCH 2012 International Conference
20th - 22nd August 2012, Glasgow, UK

PHOTOVOLTAICS AND (NEARLY) NET ZERO ENERGY BUILDINGS: ARCHITECTURAL CONSIDERATIONS

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Abstract

The energy topic has become increasingly important in architecture: since buildings are big consumers of energy and architects and the public are interested in energy as never before. [Scognamiglio 2008] The Energy Performance of Building Directive (EPBD) [EU 2010] establishes that starting from 31st December 2020 all new buildings have to be Nearly Zero Energy.

The main architectural implication for this condition is that if up until now the domain of design was the building itself, now it is the building and possibly other spaces, that have to be conceived for placing the energy generation devices. Photovoltaics (PV) is particularly suited for reaching the (Nearly) Net ZEB status, due to its technical features, the existing knowledge on how to use PV in buildings, and since it is the easiest and most reliable way to get the (Nearly) Net Zero Energy objectives. [Torcellini 2006]

A relevant international effort on the subject of the Net Zero Energy Buildings (Net ZEBs) - Net ZEB meaning that the buildings are connected to an energy infrastructure - is ongoing in the International Energy Agency (IEA), joint Solar Heating and Cooling (SHC) Task 40 and Energy Conservation in Buildings and Community Systems (ECBCS) Annex 52, titled "*Towards Net Zero Energy Solar Buildings*" [IEA 2008a].

The authors of this paper, all participating in the IEA research group, investigate how the use of PV for Net ZEBs can influence the building's design, taking into account different building typologies (e. g. new ones vs. existing ones, listed buildings, etc.). Similarities and differences between PV and Solar Thermal (ST) are discussed, too. The paper results in defining some architectural issues for using PV in NZEBs design, which implie to re-think the way buildings are designed.

Keywords:*(Nearly) Net Zero Energy Building, Architecture, Photovoltaics, Listed buildings, Cities and energy self sufficiency.*

Introduction and background

The recast of the EPBD establishes that starting from the 31st of December 2020 all new buildings have to be Nearly Zero Energy Buildings. According to this Directive, Nearly Zero-Energy Building means *a building that has a very low energy yearly energy consumption, which can be achieved by both highest energy efficiency and by energy from renewable sources, which shall be on-site or nearby* [EU 2010].

In a near future, buildings will be designed to need very little energy (due to passive design strategies and high energy efficiency), and to integrate active surfaces (e.g. PV modules) for generating energy. As a consequence, design has to consider not only the floor area we use directly, but also the space required to provide for electrical and thermal energy from renewable sources: the surface necessary for placing the energy generation devices. This area can be defined as the "building's energy footprint", and it will have to be considered in the domain of design.

As will show, designing the buildings and their energy footprint is the big challenge that architects and designers have to face in the future. The way this challenge will be taken up will influence a lot our habitats, cities and landscapes of tomorrow. [Scognamiglio, Ossenbrink, Annunziato, 2011]

Figure 1: Nieuwland, Amersfoort (NL), 1999. Pitrus-Mattenbies project, design: Klaus en Kaan. 119 houses, showing 2462 m^2 PV used as roof cladding. Source: A. Scognamiglio

Among the energy technologies, which can be used to get the Net Zero Energy objective, PV has many potentialities, thanks to its features and enormous recent decrease in cost:

- PV can contribute significantly to the reduction of the primary, conventional energy supply, as well as to the reduction of the CO_2 emissions;
- PV can power any kind of energy request of the building (electrical and indirect even thermal);
- PV can be used exactly where the energy is consumed (on-site energy generation);
- PV can be easily added or integrated onto/into the building envelope, allowing for a number of functions: e.g. on/in rooftops, opaque and semitransparent envelope surfaces, having a structural function as well as sun-shading and cladding function, etc., and enabling also a construction costs reduction if used in substitution of traditional building materials (figure 1). [Bosco-Scognamiglio 2005, Scognamiglio 2009a]
- PV can be considered in terms of price/m^2 as a “standard” material for buildings with the advantage of generating energy. PV modules are available at the price of about 1,5 EUR/W (in the only European market the price is even lower, with the lowest price about 0,78 EUR/W) and they account for about 35% ÷ 40% of the whole PV system cost. [Solarbuzz 2012] If we assume that a module has a power density of 120 W/m^2, then 1 m^2 PV modules costs about 180 EUR/m^2, and generates in European countries about 90÷160 kWh/m^2/year (table 1).

These considerations on the potentialities of PV in achieving an equalized energy balance suggest a simple architectural implication: PV is going to become an indispensable material for buildings, with the consequence of being in a near future a relevant part of the building design. [Scognamiglio 2011]

Table 1: energy production for 1 m^2 PV module, optimal tilt and azimuth angles for the selected latitude, power density 120 W/m^2. The estimation is based on JRC PVGIS calculations for 1 kW$_p$, crystalline silicon technology (8,3 m^2 PV modules surface) [JRC PVGIS].

	Rome (tilt 36°, azimuth -1°)	Berlin (tilt 33°, azimuth -3°)	Oslo (tilt 32°, azimuth -1°)
Average sum of global irradiation received by the modules, total for year (kWh/m^2)	1680	1150	1000
Average monthly electricity production by 1 kW$_p$ system, total for year (kWh/year)	1260	877	778
Average monthly electricity production for 1m^2 crystalline silicon PV module, total for year (kWh/m^2/year)	152	105	120

What are the possible architectural implications of this shift?
In the following will analyze the concept of Net ZEB, and its relationship with the architectural design, so to emphasize potentialities and challenges in using PV in Net ZEBs.

1. The Net ZEB concept(s)

Since the early 1990s various buildings and estate projects have been built all over the world which claim to achieve a (completely) balanced annual budget for the operating energy or carbon emissions.
As investigated in the IEA research group, in the past twenty years a variety of actors created projects according to different balance approaches. Until now more than 300 known projects were developed all over the world, but for defining such buildings as Net ZEB a wide variety of definitions was used, with the consequence of having many balance approaches and many solution sets [Musall 2010; Musall 2012a]. In particular, depending on the point of view, there are several ways to define Net ZEBs: they are called "(net) zero energy building", "carbon-neutral home", "equilibrium building" or even "energy plus building" [Voss Musall 2011]. In the following, will describe the main issues to consider in defining a Net ZEB.
Initially Net ZEBs have a simple, common goal, which is a neutral result for an energy or emission balance, which should be achieved in the very most cases in a period of one year.
It is normally reached at the individual building level by a two-step concept: (1) reducing the energy demand (by energy efficiency and passive measures) and (2) generating energy (e.g. by PV, combined heat and power plants (CHP), wind turbines or ST collectors).
The modifier "Net" indicates that the goal of the ZEB refers to a calculated balance between energy demand/supply and energy generation/export to grid(s). The identified balance concepts behind these buildings are hardly comparable, do normally not represented national standards and differ in the following categories [Sartori 2012]:

1. Choice of an "indicator" (final energy, primary energy, equivalent carbon emissions, energy costs, etc.);
2. "Accounting system" (classification of energy demands sectors which are included in the balance: e.g. space heating, domestic hot water, cooling, air conditioning, auxiliary energy, lighting, central services, appliances, plug loads, embodied energy, etc.);

3. “Conversion factors” with respect to the chosen metric (national or political factors, asymmetric weighting factors or time dependent conversion factors, etc.);
4. “Normalization” (suitable reference area like usable, treated, net or gross floor area or person, building or gross respectively net volume);
5. “Balance period” (regulation of the time in which the equalized balance should be achieved, e.g. life cycle balance year or month).

A further, sixth category relevant for the ZE approach and the building’s design is the definition of the “balance boundary”.

2. Balance boundary vs. energy supplies for Net ZEBs

2.1 Balance boundary

The balance boundary defines both the physical boundary of the project which is part of the energy balance consideration (single building, cluster of buildings or even in wider agglomerates) and the generation sectors, which clarify which renewable energy options are considered and how.

A broad frame (e.g. cluster of buildings) implies a synergy between several buildings, which are not necessarily Net ZEBs as singles but as a whole: buildings with a positive energy balance can compensate the ones with negative balances.

Figure 2: Net Zero Energy Buildings Cluster : Plus energy settlement in Freiburg (DE), design: Rolf Disch. The Plus Energy Settlement in Freiburg is an example where the zero energy balance is achieved in the frame of an estate. Some of the 59 built terrace houses have a positive, others a negative primary energy balance. The average is clearly positive. The efficient row houses are covered with 3150 m² of roof top integrated PV generators. The heat is supplied by district heating. The efficiency of the houses bases on the Passive House concept, and a consequent (urban) planning for shadow-free south orientation, position and shape of the buildings. Source: Rolf Disch.

This approach is possible in the case of new buildings and districts design (figure 2), and it is particularly suited for projects on existing buildings or cities (figure 3). In particular, in the case of interventions on existing buildings in “dense” cities, where the surfaces for placing the energy generation systems are limited, very often a single building cannot reach the Net ZEB balance on its own. Generally, the energy demand is high (obsolete envelopes or vertical buildings with high density of energy consumption), compared to the available surfaces for solar systems, and the effect of shadow limits a lot the use of the envelope surfaces. A possible solution here is designing new building to produce an energy surplus to compensate negative balances of refurbished buildings.


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Figure 3: Net Zero Energy Buildings Cluster / retrofit projects. Renovated district in Bad Aibling (DE), design: Schankula-Architekten. New buildings generate an energy surplus to compensate negative balances of refurbished former military accommodation buildings from the 1930s. ST and PV areas differ significantly from each other. The shown example feed heat into the settlements local heating grid by means of 2000 m² of ST collectors. Source: Schankula-Architekten.

2.2 Energy supplies for NZEBs

In relation to the architectural building design, the possible renewable supply options are [Marszal 2010; Sartori 2012]:

- in building's physical footprint (e.g. PV on a building's roof);
- on-site renewables (e.g. PV on roofs of a parking lot or small scale wind turbines);

and:
- nearby renewables (e.g. systems close-by financed by the building owner or user, such as shared CHPP);
- off-site renewables for on-site use (e.g. biomass);
- purchased "green" energy from contracts, off-site wind turbines (electricity) or CHPPs (electricity, heat and cold).

The focus for the design of Net ZEBs should be conceiving the building and its energy balance together. This implies that the energy generation should be in the building's property, which means any arrays, which could be located in the buildings footprint or on-site. [Torcellini 2006, Voss 2011, Musall 2012b, Sartori 2012].

If PV is the only energy technology used (all electric), then there is a strong relationship between the architectural form of the building and the energy choices. For instance, if we take into account a small residential building, and we imagine to optimize tilt and and azimuth angles of a PV collector, then the result could be a sloped PV plane placed on the building (figure 4).
In reality, in most cases where the building is more than one or two floors, the repertoire of solutions for PV is broader and more complex.
It is quite obvious that when using only PV, expanding the energy balance boundary beyond the building's physical footprint is necessary in many cases, when the energy demand is high compared to the available building's surfaces for solar caption (e. g.: buildings in dense cities, retrofitting buildings. This option, now considered mainly as a

technical issue, should be considered in the future as a part of the building's design, or rather, of the landscape design. By appropriate choices, in fact, it is possible to design, for instance, a solar strand detached from the building (on-site), but conceived as a part of the landscape (figure 5). [Scognamiglio Røstvik 2012]

Figure 4: CAPA (2003), Matosinhos, PT, design: Cannatà&Fernandes. The PV generator is shaped as a sloped plane that characterizes the image of the building. Source: A. Scognamiglio.

Figure 5: On-site energy generation as a part of the landscape design. The Solar Strand, Buffalo University Campus, Buffalo (US), 2011, design: Walter Hood, Hood Design. The solar array powers the existing dormitory of the Campus.The PV modules on the ground are arranged according to a DNA pattern. They give form to a public space in a direct functional and visual relationship with the buildings of the campus. Picture ©2012 University at Buffalo.

The on-site supply options for (Nearly) Net ZEBs are very multifaceted (figure 4).
Because the aim of Net ZEBs constitutes a great challenge and PV systems will not be sufficient to cover the demand alone, maximum energy efficiency and expansion of renewable energy supply is the key to success. Significant use of wind power directly at the building is limited to a few special cases because the potential is low. [Voss Musall 2011]

By contrast, building-integrated CHP offers the option to export electricity beside heat is generated and thus to gain credits offset against the energy supply. This is especially true for systems running on biomass (lower primary energy conversion factors). CHP is often used in larger residential projects and is also an option for non-residential or renovated buildings. From the building integration point of view solar thermal collectors are comparable with PV systems. But only a very few buildings examples are known where big ST collector arrays generate a large amount of heat which is feed into local heating grids to compensate the buildings own electricity supply in an annual primary energy balance [Voss Musall 2011].
Whatever the case no real Net Zero Energy building exist without PV.

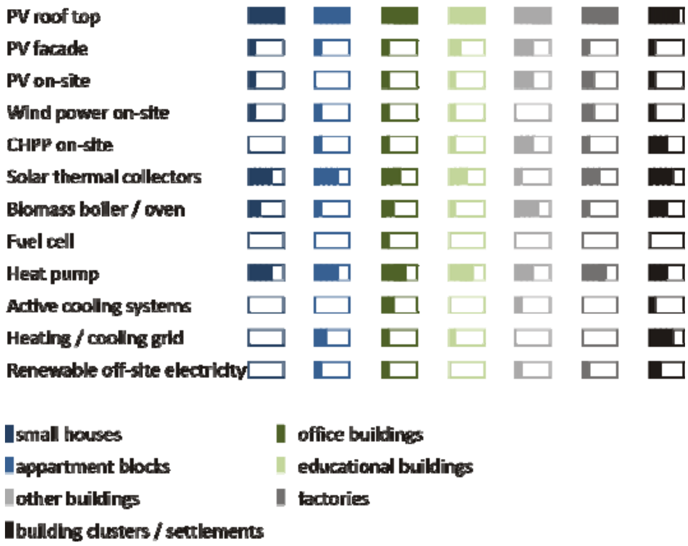

Figure 5: Matrix of used supply and generation systems. The study of approximately 200 out of the 300 known Net Zero Energy Building projects from European and North American countries (IEA Task 40-Annex 52) dealing with the utilization of renewable energy generation/supply technologies divided in different building typologies shows that all those buildings use PV. It should be recognized that not only electricity generation technologies are mentioned while renewable generated heat normally is not used to compensate electricity supply but the other way round. In all-electric building concepts (no second energy carrier) it is often used in combination with solar thermal collectors and heat pumps. Source University of Wuppertal, compare to [Musall 2011]

3. Building Integrated energy supply options: Photovoltaics vs. Solar Thermal

Table 2 summarizes the energy demand for a single town inhabitant, and energy yield for selected renewable technologies (JRC calculations, and the surface area requirement for each energy supply option, which is the ration of above quantities. The surface area requirement has been defined as the “building’s energy footprint”. [Scognamiglio, Ossenbrink, Annunziato 2011]
As results from table 2, for an “average” standard building (energy consumption 100 kWh/m^2/year) in a moderate region of Europe, the surface required for placing the necessary energy supply (i. e. buildings energy footprint) to turn a standard building into a Net ZEBs are quite big, and their size depends on the energy system efficiencies.
Despite wind is the most efficient technology, the only two technologies that is possible to integrate easily into the building envelope are PV and ST, and their efficiencies are comparable.

Table 2: Energy demand for a single town inhabitant, and energy yields for selected renewable technologies (JRC calculations based on Eurostat 2010). The surface area requirement is the ratio of above quantities. Assumptions for calculation: room space for living: 25 m^2/cap, yearly energy consumption for heating & cooling: 100 kWh/year/m^2, yearly electricity consumption 1 MWh/cap. Wind energy yield assumes land area equals rotor area, and no additional use. [re-arranged from Scognamiglio, Ossenbrink, Annunziato 2011]

		PV	Wind	ST	Biomass Biofuels
Energy Yield (kWh/m^2/year)		100	200	112	4
	Energy demand (kWh/year/cap)	*Surface Area Requirement(m^2/cap)*			
Electricity services	*1461*	15	7	94	
Heating & Cooling	*3002*	30	15	27	720

Table 3: comparison between the energy production of PV, ST, and combined PV and heat pumps. PV assumptions: energy production for 1 m^2 PV module, optimal tilt and azimuth angles, power density 120 W/m^2. The estimation is based on JRC PVGIS calculations for 1 kW$_p$, crystalline silicon technology (8,3 m^2 PV modules surface) [JRC PVGIS]. ST assumptions are based on two technologies, flat plate and evacuated tubes. Heat pumps assumptions, based on 1 kW electric input delivering 3 kW output; COP=3.

	Rome	Berlin	Oslo
Average sum of global irradiation received by the solar collectors (kWh/m^2)	1680	1150	1000
Average annual electricity production for 1m^2 crystalline silicon PV module (kWh/m^2/year)	202	105	94
Average annual thermal production for 1m^2 flat plate ST collector (kWh/m^2/year)	400	270	250
Average annual thermal production for 1m^2 evacuated tubes solar thermal collector (kWh/m^2/year)	600	520	500
Average annual thermal production for 1m^2 crystalline silicon PV module (kWh/m^2/year) combined with a air to water heat pump (COP 1:3)	606	315	282

In buildings, especially in dense cities where space is a limited commodity, the use of a building's envelope area for catching sunshine to be converted into electricity or thermal energy requires some priority decisions as to whether it is ST, PV, or a combination that shall be applied.

Until now, in most such cases, the choice has been simple: ST to deliver heat and PV to deliver electricity.

Figure 5: The "Solar Academy" in Niestetal (DE), design: HHS Planer + Architekten. The 1400 m² building was built in 2010. The idea of an "island operation" increased the PV capacity. The combination of façade, roof-top and on-site trackers ends in 152 kW_p (complemented by a 70-kW_{el} biogas CPH and a 230-kWh battery pack). Source: SMA, Constantin Meyer

Figure 6: Efficient building by a compact structure or more solar usable surface area? Rainbow Headquarters, Loreto (IT), design: S. Bianchi & E. Straffi. PV modules are arranged as wings hanging over from the building's physical boundary. Picture © L. Filateci.

Nevertheless, in the future this standard approach might have to be reconsidered: it might be more practical to deliver all energy from PV and rather use PV electricity in combination with heat pumps to power the heating and cooling demand.
In table 3 a comparison between the energy production of PV and ST for different locations in Europe is shown, and, also, the energy production of PV combined with heat pumps. This solution is very effective, but it is worth to note that this implies additional investments and operating costs (e.g. maintenance). Furthermore, very performing COP value are possible only in the case of ground source heat pumps, whereas in most cases the COP of air to water heat pumps is in the range of 1:2.5 ÷ 1:3.5.
The effectiveness of PV to power all the building's energy demand can be increased by using appropriate technical solutions, and coupling PV with other energy generation systems (figure 5).

If we move from the energy perspective to the architectural one, the “all-electric approach” has some advantages. Architects will find it easy handling only one type of material (PV) instead of several ones (PV and ST), which should result in a system of different grains, color and module size. As shown above, before such decisions are made, it is however necessary to evaluate the energy need of the building, the energy supplied from either system, and the envelope area that either system will occupy in order to perform.

One possible discussion arises from these considerations: efficient building by a compact structure (low surface to volume ratio) or more solar usable surface area? [Musall 2012c]

Obviously the decision on the envelope design approach has to take into account the local climate and the right solutions for that climate. For example, in South Europe, where an important design issue is protecting the building from the sunshine in warm and hot seasons, sun-shading systems (which extend the building beyond its physical boundary) are very diffuse. Moreover, very often the building is designed so to have some intermediate buffer spaces between inside and outside (a typical example are the traditional courtyard houses in Italy). In such cases it is not surprising that PV wings can stick out of the building’s envelope to catch the sunshine (figure 6). [Scognamiglio 2012b]

4 (Nearly) Net ZEBs scenario, PV and architectural issues

4.1 PV for Net ZEBs as it results from the IEA Task 40-Annex 52 investigation

As shown above (paragraph 1), it seems not possible or at least useful to create a Net ZEB without use of PV systems. This influences the buildings shape or the use of the site if the systems are installed outside of the buildings footprint (e.g. as tracking systems or additional open field structures). Because of that it seems to be important for the design process to know how much PV must be installed and how much surface or site area must be available. Beside the question if the building is solely supplied by PV this depends on the climate (radiation), the site situation (shading, orientation), the chosen PV technology (mono or polycrystalline cells), and above all on the energy demand of the building and hence also on the balance approach (see above). Herein the accounting system classifies the energy demands sectors which are included in the balance.

Within the framework of the IEA research, data were acquired and analysed from more than 300 worldwide known Net ZEB projects around the world. [IEA 2008] All types of building categories and sizes are represented. Most of the buildings are located in heating dominated climates in Europe and North America (figure 7). Some examples of existing buildings that were renovated to meet the net zero-energy building criteria are also included. The database gives the chance to point out how much PV is normally used in built examples depending on the points mentioned above.

The study shows that an average small residential building use almost 22 W_p/m^2_{NFA} (0,18 m^2/m^2_{NFA} at a PV power density of 120 W/m^2) to balance the energy consumption sectors according to EPBD (space heating, domestic hot water, cooling, air conditioning, and lighting for non-residential buildings). If the complete primary energy consumption is considered (including plug loads, etc.), this figure is doubled (almost 40 W_p/m^2_{NFA} or 0,36 m^2/m^2_{NFA} at a PV power density of 120 W/m^2).

In larger residential buildings or housing estates the PV systems are, in relation to the living area, in average about half the size of those in single family houses. This is due to the fact that here heating systems are used which lower the overall primary energy demand (e.g. by a higher efficiency or use of biomass) or CHP systems, which also generate electricity locally.

Figure 7: A world map shows an output of the internal IEA projects database system and localizes more than 300 known Net Zero Energy Buildings (each typology with an own color). The map with additional buildings information is available under [IEA 2008].

Office buildings require a PV capacity of around 7 W_p/m^2_{NFA} (0,05 m^2/m^2_{NFA} at a PV power density of 120 W/m^2) to equalize their primary energy balance if only the EPBD related energy demands are included. If the demand is expanded by “user specific” consumptions this value growths to 27 W_p/m^2_{NFA} (0,22 m^2/m^2_{NFA} at a PV power density of 120 W/m^2. While factories have a similar value (21 W_p/m^2_{NFA} or 0,17 m^2/m^2_{NFA} at a PV power density of 120 W/m^2) this varies greatly in educational buildings depending on the type of use (school, academy, or nursery) as shown in figure 7. Generally in refurbishment projects larger PV plants are used. CHP, wind power or buying “green” electricity is usual and mostly necessary in large, non-residential buildings [Voss Musall 2011].

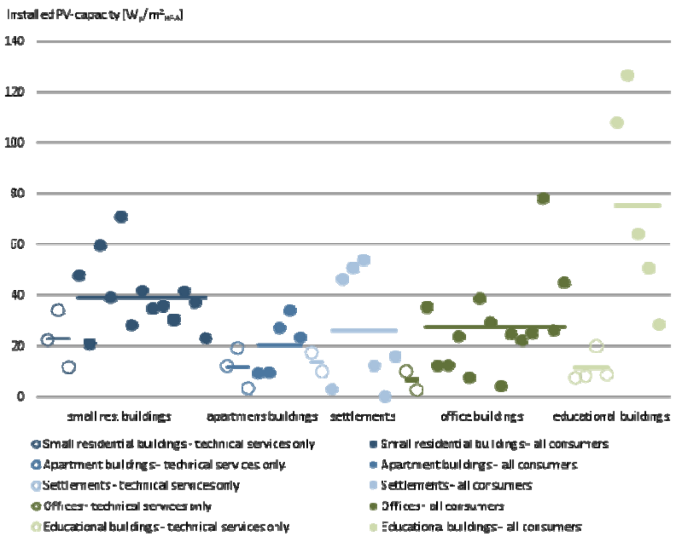

Figure 8: IEA Task 40-Annex 52 case studies analysis. Installed capacity of PV systems per m^2_{NFA} (Subdivisions in buildings which balance includes the technical building services only or all energy consumers). Source: University of Wuppertal [Voss Musall 2011]

4.2 Challenges for the use of PV for Net ZEBs

From the technical point of view, the main obstacles to face are intrinsic in the Net ZEB target compared to the features of the PV technology.
There is a limit to how much energy can be generated per m^2 PV collector (depending basically on the PV efficiency, on the tilt and azimuth angles of the PV generator, on the latitude, as well as on the BOS efficiency). As a consequence, due to the low energy density of PV, the building envelope might not be sufficient to generate all the energy the buildings needs.
These considerations lead to a possibility of using PV in proximity of the building when the envelope surfaces available for PV are not large enough for achieving the Net ZEB balance. Moreover, a ZEB, when connected to the grid (Net ZEB) might have a fully matched annual energy balance, but in the case of PV, the load match (the fraction of electricity directly consumed) is in the range of 30%, or even less. [Voss 2010] For this reason it could be favourable to feed electricity into a grid for nearby consumption in another building. This implies that the issue of PV in ZEBs should be discussed on the level of the building as well as on the level of the buildings cluster or at the urban scale.
This condition points towards an architectural focal point of the discussion that this paper would like to open: the need of investigating the use of PV in ZEBs from the architectural scale (one building) to the urban scale (a cluster of buildings) or, even, to the landscape scale.
An analysis of 30 case study buildings from ten countries documented in the IEA SHC Task 40 - ECBCS Annex 52, revealed that the buildings' solar PV systems were mostly delivering only a small fraction of the total energy need (very low match).

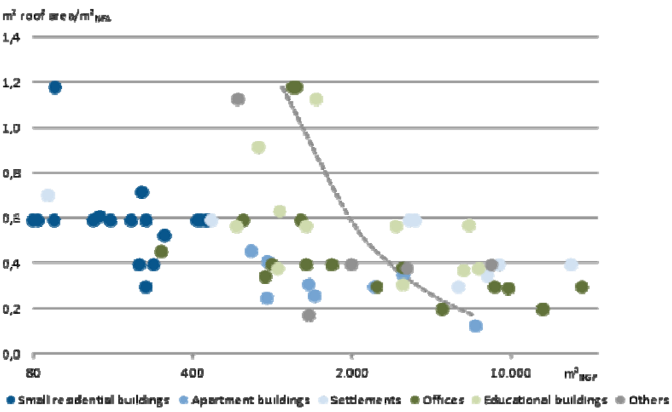

Figure 9: The potential of roof surfaces for the solar generation of energy/electricity (here flat roofs for reasons of simplicity) in relationship to existing net floor area of known Net ZEBs in heating dominated climates. For projects with a higher energy demand (non-residential or renovated buildings) the useful roof area decreases in comparison to the net floor area. For contemplation purposes the line shows the theoretical increase of usable floor area with an increasing number of storeys and a constant roof area. Source: University of Wuppertal, compare to [Voss Musall 2011]

In spite of this, in many cases the PV modules were sticking out the building's footprint, in a way that the design challenges had not been adequately addressed.
Nevertheless conceiving a PV system in a Net ZEB so that its formal result is satisfying should be possible, and it is a further step for research on the use of PV in buildings.
It is worth to note that the Net ZEBs scenario changes the context for the use of PV in buildings. Until now, in fact, the main architectural challenge was how to use PV in a satisfying, pleasing, way [IEA 2008b], whereas in the case of Net ZEBs, the use of PV has to be calculated on the building's energy demand, and this implies generally bigger surfaces than in the past, and an increased attention to the energy performance of PV

(optimization).
The attention paid to the energy efficiency of the building, together with the improved efficiency of PV modules, will help in including PV in the buildings design (e. g. by reducing the surface area of PV modules needed).
A chronological view of smaller residential Net ZEBs exposes a tendency to reduced sizes of PV systems during the last years. Improved efficiency of PV modules and lowered demands of the buildings will move forward this trend.
The necessity of this is shown by the fact that so far, Net ZEBs have not been built extremely dense, but mostly very flat. Net ZEBs with more than three storeys are rare, as larger floor area mean higher consumption and, proportionately, a smaller PV area per net floor area (figure 9).
It seems important that in the future in the development of new PV components for Net ZEBs integration, the energy performance of the system as a whole is taken into account (e. g. roof systems with high energy performance as insulating materials).

4.3 The use of PV in listed buildings

Developing innovative approaches to energy retrofitting of existing and listed buildings is necessary in order to avoid several of them from becoming technically obsolete which leads to rising energy running costs and finally in some cases demolition.
Furthermore, from an economic point of view, the energy production, can be an occasion to earn a budget useful for the building's maintenance and operation. For instance, there are several cases in Italy, where, being the feed in tariff for building integrated Photovoltaics very effective, public schools (big surfaces for PV) can earn money by selling the energy they generate.
In the energy retrofitting of existing buildings several challenges appear, most of them related to merging the technical systems with the construction and with the architecture. Establishing solar systems on buildings or nearby is a design challenge that can be handled but only if care is taken; the possible design approaches depend very much on the cultural heritage legislation that varies in different countries.
There are examples of attempts at addressing this issue in a serious way where the necessary design input have been applied for the purpose of a complete rethink of alternative strategies. Architects who retrofit existing buildings are to the best of their ability normally trying to handle existing constructions with care and to add positive elements of architectural merit to them where possible and necessary. This is the case of historical, but not listed buildings, even if part of a listed area of a city or of a landscape, where it is possible to transform parts of the building envelope (figure 10 and figure 11). [Scognamiglio 2009b]
But, in the most extreme cases where existing buildings are protected by the antiquarian authorities as listed buildings it is very often impossible to change any part of walls or roofs. The envelope will remain static. In such cases, definitely in Grade 1 listed buildings any energy producing system will have to be positioned at a distance from the listed buildings or invisible (e. g. CHP inside the building). In many countries there is in addition a "banned zone" around the building, at times this zone is defines by a 360 degrees and 60 meter distance (radius) from the building.
There are examples of attempts at addressing this issue in a serious way where the necessary design input have been applied for a complete rethink of alternative strategies.
In this case, the only possibility is considering on-site energy generation systems, designed to be in a formal relationship with the building, and as a part of the site design (figure 12).

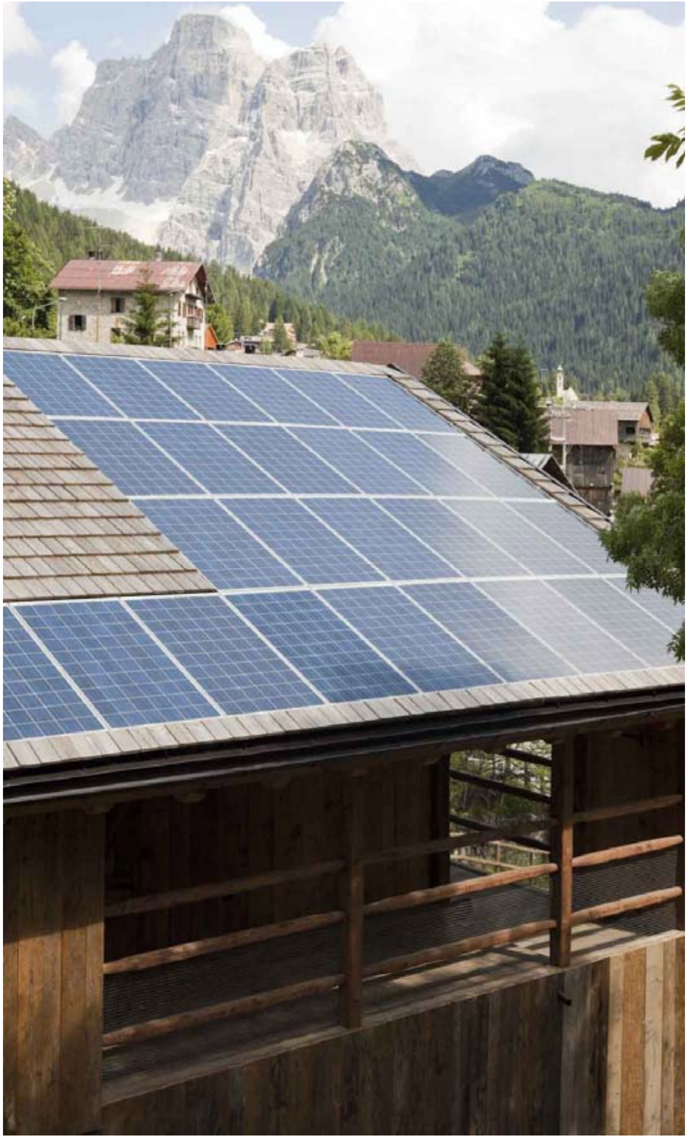

Figure 10: PV on building's (listed site) / Energy self-sufficient tabià (retrofit), Selva di Cadore (Belluno), IT, 2010, Design: EXiT. PV is part and parcel of the pre-existing wooden tilted roof. *Tabià* are named old buildings (XVII century) used as a stable or barn, which characterize the agricultural and pastoral architecture of the Selva di Cadore Valley in the landscape of the Italian Dolomites, classified as a UNESCO World Heritage site. One of these buildings was renovated and transformed into an energy self-sufficient holiday home thanks to PV, which supplies heat, hot water, cooking systems and other electrical appliances. Picture ©T. Cos.

When it is not allowed to modify the building's envelope (BAPV-Building Added PV or BIPV-Building Integrated PV), then the solution can be the design of a sculptural element, placed at a certain distance from the building, and in formal relationship with the building itself. Such an approach at developing solutions for existing buildings does uncover the need for more information and will in the near future include a new understanding and possibly a new research into ways of elegantly establishing ways of developing renewable energy catching systems for many kinds of preserved existing buildings.

Figure 11: An ordinary historical building in Rome, transformed into an energy generating building (Reinverso). Design: R. Russolillo, D. Lucafò. S. Chiergia; work developed at the Italian Institute of Architecture, Master Progettista di Architetture Sostenibili, 2009. From left to right: the existing building, the re-designed South facade, and the re-designed North facade. Source: InArch, Italian National Institute of Architecture

Figure 12: PV on building's site(listed building) / Hol Church, Geilo, NO, design: Harald Røstvik. What do you do when you for antiquarian reasons are not allowed to do anything on the built envelope? An extensive search for alternative solutions did lead to the circling in of using the extended space around the church for energy producing, solar absorbing, purposes. A vertical ST absorber at a distance to the building, as a sculptural feature. The solar absorbing sculpture was designed in dark green so as to blend with the green forest next to it and hence not steal too much attention from the red church it was supposed to serve. A dark green solar absorber is less efficient than a black one, but only slightly and the loss in efficiency can easily be compensated for through increasing the solar absorber area by 10-15 percent. Source: H. Røstvik

5. Preliminary conclusions

The investigation results in some important issues for the use of PV in (Nearly) Net ZEBs scenarios, which have an influence on the building and city design.

When designing a building, the energy demand has to be reduced as much as possible (passive strategies and energy efficiency), to keep its energy footprint (the surfaces required for placing renewable energy generation systems) within its physical boundary.
This is important not only from an energy perspective, but from the practical design point of view (existing building regulations), too. The development of new PV components will have to consider the thermal features as parts of the new data-sheets.
When designing a cluster of buildings, the possible relationship between single buildings has to be taken into account to design a Net ZEB balance for the cluster. The energy boundary and the project boundary have to be in a close relationship which should be from the architectural point of view not only a technical issue, but should also be exploited as a design possibility.
It is easy to understand that in the future design as well the urban planning regulations will have to consider the building's energy footprint as a part of the design. It is a big shift since the traditional architectural design is used to conceive in terms of design only the space we live in. It does not conceive the energy requirements as an input for architectural design, but rather a mandatory issue imposed by law.
Due to its features and potentialities, PV is to consider an indispensable technology when design a new building, and when dealing with the renovation of an existing building or district. Nevertheless, the use of PV has many challenges to face; among these it is very important the ability of dealing with the design of Net ZEBs and cluster of buildings not only at the architectural scale (energy generation in buildings footprint), but at the site and landscape scale (on-site energy generation), too. This means considering the cluster as a system, according to an ecological perspective.
Until now designing Net ZEBs has been possible mostly in the case of sites with a low density, so that the available surfaces for PV can be commensurate on the building's energy demand. This circumstance seems to foster towards the development of new "diffuse" cities. Nevertheless, pro and cons of dense and diffuse cities are very well known, and it seems that dense cities present several advantages (more efficient urban land use, transport and infrastructure). Furthermore, many European countries present historical cities with a very dense pattern. Therefore it would be reasonable thinking of the city and its peripheral areas as a whole system, where there is an energy generating part (the external and diffuse part of the city), and an energy consuming centre.
Alternative solutions to the use of PV integrated or added into / onto the envelope have to be conceived in the case of listed buildings, where no intervention is allowed on the building's envelope. One possible solution is conceiving the energy generation systems as elements detached from the buildings, but in a formal relationship with them.
The authors would like to emphasize that none of these challenges can be taken up without a trans-disciplinary approach, which overcome discipline boundaries and barriers.

Acknowledgements
The authors of this paper would like to acknowledge all the members of IEA SHC Task 40 ECBCS Annex 52, *Towards Net Zero Energy Solar Buildings*, and the operating agent Josef Ayoub.

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